NEW TECHNOLOGY DELIVERY SYSTEM FOR FM-200® CLEAN AGENT

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INTRODUCTION

Since the promulgation, in 1987 of the Montreal Protocol on Substances that Deplete the Ozone Layer there has been, and continues to be, a wide ranging effort to discover and develop alternative technologies to serve the fire protection functions fulfilled by bromotrifluoromethane, or Halon 1301. Many new fire protection applications in the commercial, industrial, marine, aircraft, military, and other, sectors employ any of a variety of new fire extinguishing technologies that use extinguishing agents that are safe for human exposure when applied at their use concentrations. Without exception, the new "clean" fire extinguishing agents, as named in relevant US [1] and international standards [2] must be used in greater quantities, however measured, than Halon 1301 for a given total-flooding fire extinguishing application in order to achieve assurance of fire extinguishing performance. This fact means that in developing the design of a fire suppression system accommodation must be made for larger quantities of agent than would be required with the use of Halon **1301.** Thus, the storage banks of the new agents require more agent container storage capacity with more total weight and occupying more floor space than if Halon **1301** were used. Additionally, the systems used to deliver the new agents to the distribution nozzles, located in the protected space, will consist of pipe of a larger diameter or heavier gauge, or both, than would have been required with a Halon 1301 installation. The total installed cost of a system to deliver a halon alternative clean agent is considerably greater than an equivalent Halon 1301 system due to the combined incremental costs of increased agent mass, container capacity, pipe system size, and installation costs. Thus, with the high total installed cost associated with use of the new clean agent technologies it is little wonder that in many cases applications formerly served by Halon **1301** are served with not-in-kind alternative fire protection means. Yet, the demand for new clean agent fire suppression systems is robust. This is a testimony to the evolution of the commercial sector's increasing reliance on halon-like suppression technology, which upon discharge, will suppress fires rapidly while resulting in no or negligible collateral damage, thus minimizing the interruption in high value business activity and preserving extremely valuable physical assets. Perhaps most importantly are the human safety aspects of clean agents. The commercial success of clean agent technologies is an affirmation of the importance society places on the protection of people in the rare instance where a suppression system is caused to discharge unexpectedly in an occupied room.

While the new clean agents, most notably hydrofluorocarbons like HFC-227ea (FM-200®) and inert gases (Inergen, Argonite, and others) have become well established in new installation applications, there remains the vexing problem associated with the use of these new technologies to replace Halon **1301** in an existing installation. In some instances it is economical to simply remove an existing Halon 1301 system pipe work and install a new pipe system sized in accordance with the requirements of the manufacturer's approved manual and flow calculation method. In a number of other cases removal or replacement of existing pipe networks will not be economically feasible, or even physically possible, due to the complexity of the overall structure that now encases the pipe network. Alternatively, re-working an existing installation may be prohibitively costly or require unacceptable interruption of ongoing operations. There are thousands of existing Halon **1301** systems for which a true retrofit solution is needed.

Where the nature of an original Halon 1301 installation demands a true retrofit system, a satisfactory solution will be one that meets four principal requirements: (1) the replacement agent supply must fit in the space available; (2) the only permitted pipe system modifications are ones at the point of connection to the agent supply; **(3)** a change out of agent distribution nozzles; and (4) the resultant system must meet the critical fire extinguishing performance requirements called for in today's standards, the most notable of these being achievement of the required discharge time, nozzle pressure, and mass distribution at each nozzle. Given the significance of the characteristics of the pipe and fittings on the overall hydrodynamics of an agent delivery system, it is little wonder that achieving a true retrofit is a tall order.

This paper is about the development, by Kidde-Fenwal. of a new technology delivery (NTD) system for FM-200 clean agent. This new delivery system has been under study and in development since 1995. After thorough study it has been determined that the system will be an effective retrofit solution meeting the four requirements noted above. What follows is a discussion of some basic elements of the science of the delivery of Halon 1301 and the FM-200 clean agent using both traditional and the new delivery technologies.

HALON 1301 RETROFIT - AN EXAMPLE

The challenge offered by the Halon 1301 retrofit problem can he best understood by considering an example. Consider the protection of a 20,000 ft^3 room containing a **Class** A fire hazard. The design of a standard Halon 1301 pipe system [3] that might service such a room is shown schematically in Figure 1. The principal suppression system design parameters are given in Table 1. Significant features of the Halon 1301 system design in this case are the agent discharge time and the average nozzle pressure. The discharge time is 10 s, the maximum allowed by NFPA 12a [4]; the average nozzle pressure of 100 psig is the minimum permitted in accordance with the approved operating limits of the system. As such, this system design will be referred to as a "limit" system.

Now consider the installation of a retrofit clean agent suppression system, one that would employ the existing Halon 1301 pipe network. None of the approved clean agent systems on the market today is capable **of** fulfilling the retrofit requirements. The agent quantity and flow rate requirements can not be accommodated by the existing Schedule 40 pipe system while achieving the critical performance requirements, namely a discharge time **of** 10 **s** or less and achieving the minimum listed or approved nozzle pressure while at the same time not exceeding the pressure rating of the pipe. The result obtained when applying approved design methods for a standard Kidde FM-200 clean agent system is illustrated in Table 1. The discharge time of 22.3 s exceeds the 10 s limit; the average nozzle pressure of 58 psig is below the listed /approved value of 72 psig. Thus, this solution fails to meet two critical design criteria.

The limitations of the standard FM-200 delivery approach in the retrofit application can be overcome through use of the new technology delivery system. The advantage offered by the NTD system are understood by considering the physics of the fluid flow in a halocarbon suppression system. Specifically, consider the behavior of the agent as it starts out at the storage container and flows through the pipe network to the nozzles. As a fluid element of superpressurized agent undergoes a change in pressure, starting at 360 psig in the storage container and passing to lower pressure during the course of pipe flow, the density of the flowing "agent" decreases. The initial condition of the agent is **as** a single-phase liquid in equilibrium with the nitrogen and agent vapor in the ullage space of the container at a total pressure of 374.7 psia at 70 "F. The in-container properties of Halon 1301 and HFC-227ea are given in Table 2. The superpressurized agents are distinctly different in three key properties:

1. Dissolved nitrogen: At cylinder storage conditions the amount of nitrogen dissolved in HFC-227ea is 75.7% greater on a mass basis than **for** Halon 1301.
2. Vapor pressure: The pure-agent vapor pressure of Halon 1301 is 152 psi greater than that of HFC-227ea.
3. Liquid density: The liquid-phase density of superpressurized Halon 1301 is 12.8% greater than that of superpressurized HFC-227ea.

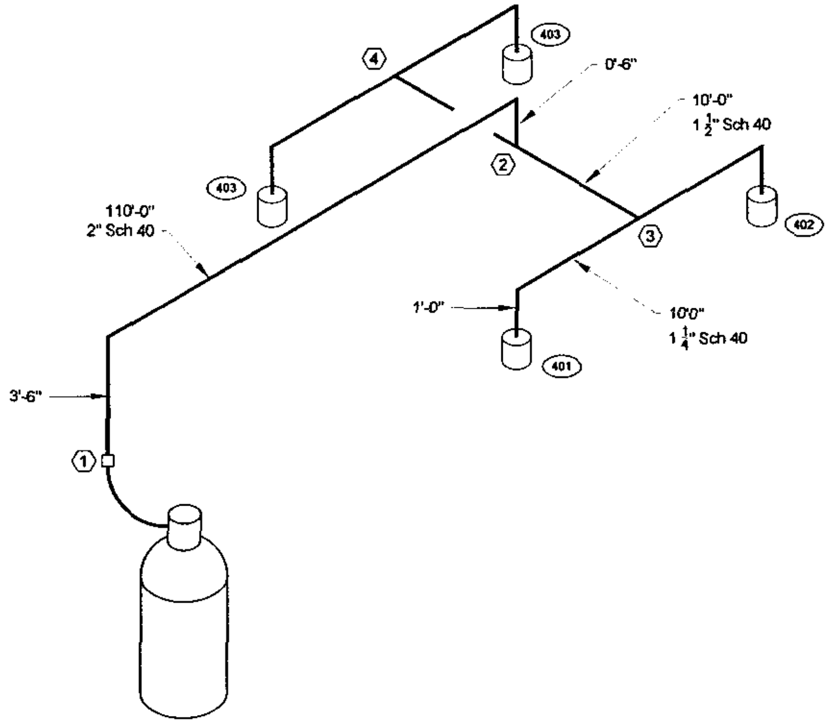

Figure 1. Halon 1301 system designed and installed to protect a 20,000 ft^3 space.

TABLE 1. COMPARISON OF HALON 1301 AND FM-200 RETROFIT ALTERNATIVES.

	Halon 1301 Super-pressurized	FM-200 Super-pressurized	FM-200 Separate N_2 20%SF	FM-200 Separate N_2 30%SF
Class A exting. conc., Vol. %	3.0	5.8	5.8	5.8
Design Concentration, Vol. %	5.0	7.0	7.0	7.6
"Safety Factor"	66%	20%	20%	30%
Agent quantity, lb.	414	684	684	742
Agent cylinder size*	"600 lb"	"350 lb"	"350 lb"	"350 lb"
Number of cylinders	1	2	2	2
Fill density, lb/ft^3	48.3	68.4	68.4	74.2
Agent cylinder pressure, psig	360	360	44	44
Pipe: cylinder / manifold to 1st tee		104 A 2 in. Sch 40 + 2 elbows		
Pipe: 1" tee to 2nd tee		10 ft 1½ in. Sch 40		
Pipe: 2nd tee to nozzle		11 ft 1%in. Sch 40 + 1 elbow		
Nozzle area, in^2	I.06	1.03	Proprietary	Proprietary
Avg. nozzle pressure, psig	100	58	100	102
Discharge time, s	10	22.3	9.7	9.9
Comment	"Limit" system	Discharge time > 10 s	Meets or exceeds requirement	Meets or exceeds requirement

* Cylinder size is stated *as* the nominal standard fill capacity for Halon **1301** or standard **FM-200** of Kidde 487 Series hardware. The design is for a hazard temperature of **70 °F** and ambient pressure of **14.7** psia.

TABLE 2. **PROPERTIES**[a] OF NITROGEN SATURATED[b] HALON 1301 AND HFC-227EA AND PURE HFC-227EA.

	Halon 1301 w/N_2	HFC-227ea w/N_2	HFC-227ea Pure
Agent vapor press, psia[c]	214.0	58.0	58.0
Cylinder pressure, psia	374.7	374.7	58.0
Liquid density, lb/ft^3	95.2	88.4	88.6
Vapor density, lb/ft^3	10.9	9.4	2.00
N_2 in liquid, wt %	0.74	1.30	n/a
N_2 in liquid, mol %	4.30	6.55	n/a

Notes: [a] **All** properties are at 70 °F. Compositions and densities calculated using *Profissy* [5].
[b] Nitrogen saturated properties are for mixtures initially superpressurized to 360 psig at 70 "F.
[c] Fluorocarbon component only.

The effect on in-pipe agent flow of these three features together, particularly the first two, is to develop and sustain much higher mass flux (mass flow rate per unit of flow cross section) in the case of Halon 1301. The effect is illustrated in Figure 2 for a constant temperature at 70 °F. The density of an element of superpressurized agent, initially a single-phase fluid, is observed to decrease rapidly as the pressure on the fluid element decreases during pipe flow. The density decrease arises from the out-gassing of dissolved nitrogen and agent vapor as required to maintain a state of vapor-liquid equilibrium. Since HFC-227ea has much lower vapor pressure than Halon 1301, the total driving pressure drops more quickly *as* the fluid density decreases. The data shown in Figure 2 are not corrected for the decrease in vapor pressure due to evaporative cooling, the effect of which would he to shift the Halon 1301 line to the left. The general principle that is illustrated, however, is still the same, namely that expansion of the superpressurized agents to a given lower density result in a lower in-pipe pressure for HFC-227ea than for Halon 1301. Halon 1301 can draw on its substantial vapor pressure **as** a source of motive force to sustain the flow with far greater effect than HFC-227ea.

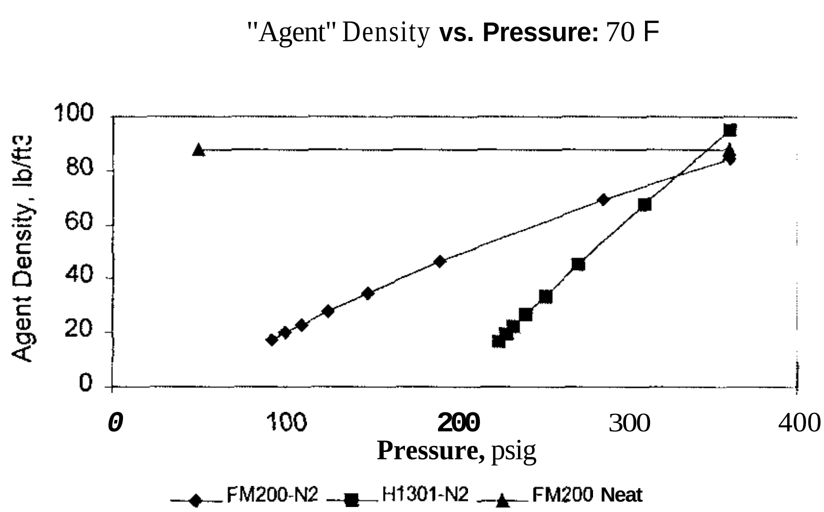

Figure **2.** Variation of agent density with pressure. Superpressurized agents at **an** initial condition of 374.7 psia, 70 °F.

Another general principle to hear in mind is that a reduction in fluid density leads to an increase in pressure gradient in a pipe. The general model of pipe flow pressure **loss** is given by

$$dP/dx \;\alpha\; \rho U^2 \text{ where} \qquad (1)$$

dP/dx = pressure gradient along the pipe
ρ = fluid density
U = average fluid velocity

To maintain a constant mass flow rate, the fluid velocity must increase in proportion with a decrease in fluid density. At constant mass flow rate and cross sectional area the velocity varies inversely with the fluid density.

$$u \propto 1/\rho \quad (2)$$

In combination with (1), the pipe pressure gradient varies in inverse proportion to the fluid density,

$$dP/dx \propto 1/\rho \quad (3)$$

A reduction in fluid density, therefore, leads to more rapid pressure drop. Moreover, for superpressurized agents the fluid density decreases with increased distance from the storage container leading to an increasing pressure gradient requiring even more energy to overcome the flow resistance. From this it is apparent that the underlying difficulties of substituting superpressurized HFC-227ea for Halon 1301, while using existing pipe network, are significant and are summarized as:

1. Substantially greater total agent mass must be pushed through an existing pipe network.
2. Available latent energy in superpressurized HFC-227ea is not sufficient to overcome the opposing pressure gradient associated with inherently low-density fluid flow and still achieve a discharge time of 10 s.

NEW TECHNOLOGY DELIVERY SYSTEM

The essential elements of the Kidde-Fenwal new technology delivery (NTD) system for FM-200 clean agent are outlined in US Patent 6,112,822 [6]. The flow limitations due to gassy low-density fluid can be substantially reduced by not superpressurizing the agent. Rather, the propelling gas can be delivered to the ullage space of the agent cylinder upon demand. The agent is then expelled from the cylinder as a pure component. Since HFC-227ea has a vapor pressure less than the pressure imposed upon it during pipe transport, the agent remains completely in the liquid state and at the pure component density. This condition is illustrated as the horizontal line in Figure *2*.

The development of the Kidde-Fenwal NTD product is well advanced. One arrangement is shown schematically in Figure 3. A separate nitrogen supply cylinder is employed. Nitrogen is supplied on demand at a controlled rate to the agent container. The pressure history in the agent container and at the nozzle can be controlled through proper selection of the key design features of the nitrogen inlet assembly and the nozzle discharge coefficient. Flow calculation software has been developed, which was used to make accurate predictions of pressure and mass flow rate through out the system. Extensive validation testing has been conducted. Features of the NTD solution, having to do with regulation of the flow rate of nitrogen propellant and nozzle properties, make Halon 1301 retrofit designs easily achievable, even for differing design goals. In Table 1, retrofit solutions using the NTD approach are illustrated for cases where the design requirement was to deliver enough FM-200 clean agent to achieve design concentrations having either a 20 or 30% safety factor, whichever may be required by the relevant standard. In each case, the discharge time was within the 10 s limit, but the agent delivery capacity of the system was not challenged.

SUMMARY

Replacing existing Halon 1301 total-flooding systems with standard clean agent alternatives is not possible if the existing 1301 pipe system must be employed. The underlying reason for this difficulty is the challenge of delivering enough agent, flowing at relatively low density, to achieve the required agent concentration in the allowed discharge time of 10 s for halocarbon clean agents. The new technology

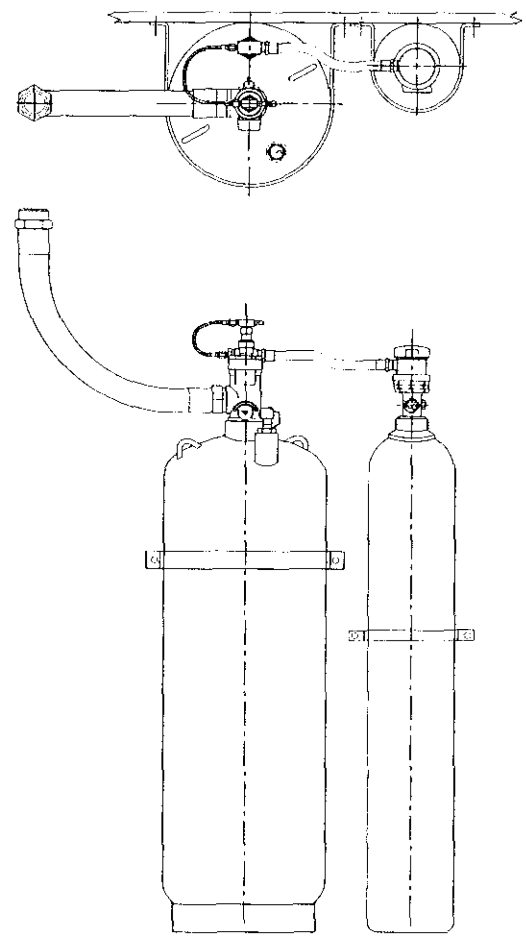

Figure 3. Arrangement of new technology delivery system components.

delivery system for FM-200 clean agent under development by Kidde-Fenwal has been demonstrated to offer a direct 1301 retrofit solution. The NTD system is fully capable of employing existing Halon 1301 pipe networks and still delivering the required agent quantity in 10 s whether the design requirement is based on a 20 or 30%, or even greater, safety factor in agent concentration.

REFERENCES

1. ***NFPA 2001, Standard for Clean Agent Fire Suppression Systems,*** National Fire Protection Association, Quincy, MA.
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3. ***487 Series Engineered Halon 1301 Fire Suppression Systems,*** Design, Installation, Operation and Maintenance Manual for Kidde-Fenwal Halon 1301 Systems, February 1, **1998.**
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6. Robin, **Mark L.,** Register, W. Douglas, Iikubo, Yuichi, and Swevel, Mark, ***Method for Delivering a Fire Suppression Composition to a Hazard,*** **US** Patent 6,112,822, Sep 5, 2000.